§5. Quantitative Evaluation of a High-speed Neutral Particle Flow for Refueling LHD by Using an Accelerated CT Plasma

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The spheromak-type compact toroid (CT) injector of SPICA (SPheromak Injector using Conical Accelerator) has been developed for advanced fueling in LHD at NIFS. SPICA was a two-stage magnetized coaxial plasma gun which has two inner electrodes and a common outer electrode. The current SPICA has been operated as a single-stage CT injector with connecting only the acceleration bank unit to the outer and both inner electrodes as shown in fig.1. Using the CT injection technique, we have recently researched production of extremely super-high speed neutral particle flow (NPF) as a new approach to effective fueling.

In this experiment[1], SPICA accelerates a CT to 100 km/s with a density of up to 1×10^{22} m^{-3} at the muzzle of the injector, and injects it into a neutralizer cell (a length of 1.8 m, a volume of 5.5×10^{-2} m^{3}) filled with hydrogen gas. Then super-high speed NPF is produced owing to charge exchange reaction between the CT plasma and the background neutral gas. For measurement of the NPFs, we used a piezoelectric pressure sensor, and a Schultz-Phelps type ion gauge with a PIN diode which detects emission from a filament as a change in pressure. For measurement of the CT plasmas and NPFs, PIN diodes (L1-4) and a He-Ne laser interferometer were positioned along the CT traveling direction. The measurement data show that a fast NPF reached the flux conserver (FC) connected to the end of the neutralizer cell, and the plasma remained with an electron density of 10^{20} m^{-3} to reach also there as shown in fig. 2. As a result, although neutralization of the CT plasma is not completed, a high speed NPF comparable to an accelerated CT has been successfully produced.

In simulation study[2,3], Gunma Univ. group has made a Monte-Carlo simulation on the neutralization of CT plasma. Numerical calculation shows that a CT plasma moves about 2 m at a speed of 200 km/s, being neutralized roughly 70%, and slow ions are trapped in a CT, tardily going out of the computational domain. The structure of the CT/NPF is different from that in the experiment. The observed CT/NPF has a high electron density region in the front part. It could be due to effect of a magnetohydrodynamic shock wave between the front and trailing parts in a CT plasma or a hydrodynamic shock wave between a NPF and neutral particles in the background. In addition, the hybrid simulation model is under development to investigate an electromagnetic behavior in the neutralization process of a CT plasma. In the model, ions in the CT are calculated as particles, while the electrons are treated as a fluid.

In the follow-on work, we intend to improve neutralization efficiency by optimizing the operation parameters of the CT injector and neutralizer cell in the experiment, and to study the influence of the axial electric field generated by the friction force between electrons in the moving CT plasma and cold ions in the background in the simulation study.

1) N. Fukumoto, *et al.*, Proc. of Plasma Conference 2011, 23P113-P (2011).
2) T. Watanabe, *et al.*, Abs. of 21st International Toki Conference (ITC-21) , Nov. 21-Dec. 1, P1-91, p. 128 (2011).
3) T. Watanabe, *et al.*, Workshop on Innovation in Fusion Science (ICC2011) and US-Japan Workshop on Compact Torus Plasma, Seattle, USA, August 16-19, 2011.

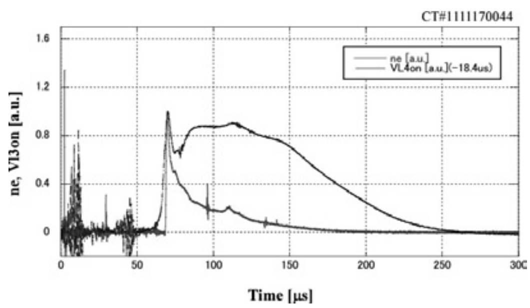

Fig. 2 An electron density and a PIN diode signal at the end region of the neutralizer cell.

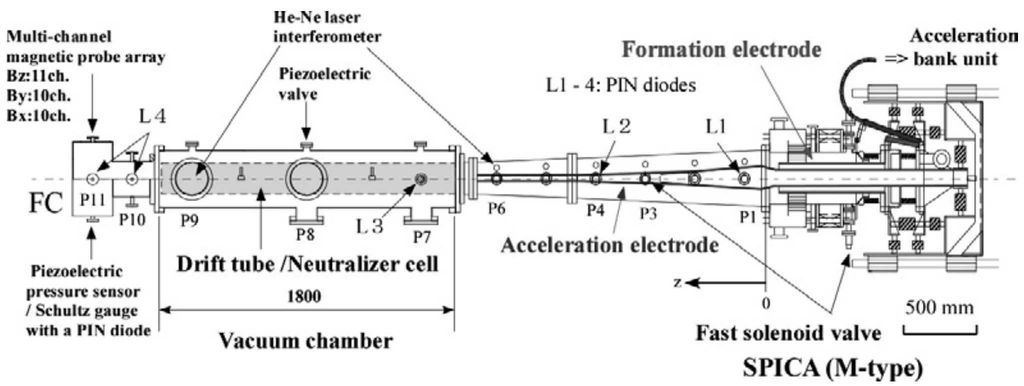

Fig. 1 Schematic draw of the SPICA CT injector and the neutralizer cell.